

# On the polarization effects in $(p, n)$ reactions between the $A = 48$ isobarical states

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## A b s t r a c t

Isotopical dependence of spin-orbit splitting discovered by us in spectra of heavy nuclei close to doubly magic ones is checked in polarization effects arising in charge exchange  $(p, n)$  reaction between the  $A = 48$  isobarical states.

Basing on the analysis of existing experimental data in nuclei close to doubly magic nuclides  $^{208}\text{Pb}$  and  $^{132}\text{Sn}$  and on different theoretical approaches it was shown in [1] that for similar orbitals the neutron spin-orbit splitting in  $N > Z$  nuclei is larger than the corresponding proton splitting. It was also demonstrated in [1] that different theoretical approaches lead to a larger neutron as compared to proton splittings of  $1d$  and  $1p$  orbits in  $^{48}\text{Ca}$ , where the corresponding experimental data on energies of single particle levels are incomplete due to strong fragmentation effects. It was shown in particular in [1], that in terms of phenomenological potential the spectra of single particle states, including the spin-orbit splittings, may be reproduced by the average potential of the form

$$\begin{aligned} \hat{U}(r, \hat{\sigma}, \tau_3) &= V_0 \left( 1 + \frac{1}{2} \beta \frac{N-Z}{A} \tau_3 \right) f(r) + V_{ls} \left( 1 + \frac{1}{2} \beta_{ls} \frac{N-Z}{A} \tau_3 \right) \frac{1}{r} \frac{df}{dr} \hat{\mathbf{l}} \hat{\mathbf{s}} + \frac{(1 + \tau_3)}{2} U_{Coul} , \\ f(r) &= \left[ 1 + \exp \left( \frac{r-R}{a} \right) \right]^{-1}, \quad R = r_0 A^{1/3} \end{aligned} \quad (1)$$

with  $V_0 = -51.5$  MeV,  $r_0 = 1.27$  fm,  $V_{ls} = 33.2$  MeV  $\cdot$  fm<sup>2</sup>,  $a \approx 0.6$  fm,  $\beta = 1.39$  and  $\beta_{ls} \sim -0.6$ ;  $\tau_3 = -1$  for neutrons and  $\tau_3 = +1$  for protons. Introducing the quantities  $t_3 = -\tau_3/2$ ,  $T_3 = (N - Z)/2$  and making in the spirit of [2] the substitution  $T_3 \cdot t_3 \rightarrow \hat{\mathbf{T}} \cdot \hat{\mathbf{t}}$ , where  $\hat{\mathbf{T}}$  and  $\hat{\mathbf{t}}$  are isospin vector operators for the core and nucleon, we obtain the nuclear part of potential (1) in the isotopic-invariant form (Lane potential), suitable for description of both the diagonal in  $t_3$  (single particle spectra and elastic scattering) and non-diagonal ( $(pn)$ -reactions leading to isobaric analogue states) processes:

$$\hat{U} = V_0 \left( 1 - 2\beta \frac{\hat{\mathbf{T}} \cdot \hat{\mathbf{t}}}{A} \right) f(r) + V_{ls} \left( 1 - 2\beta_{ls} \frac{\hat{\mathbf{T}} \cdot \hat{\mathbf{t}}}{A} \right) \frac{1}{r} \frac{df}{dr} \hat{\mathbf{l}} \hat{\mathbf{s}}. \quad (2)$$

A spin-orbit term in a potential leads to polarization effects in scattering. We see from (2) that while the polarization in elastic scattering depends on the parameter combination of the form  $V_{ls} \left(1 - \beta_{ls} \frac{(N-Z)}{A} t_3\right) \approx V_{ls}$ , similar effects in charge-exchange reactions with excitation of isoanalogue states are proportional to  $\beta_{ls} \cdot V_{ls}$ , and are thus defined by the isovector mean spin-orbit field parameter  $\beta_{ls}$ , as the  $V_{ls}$  parameter is well known. Thus we can check the conclusions of Ref. [1] concerning the  $\beta_{ls}$  value and based on nuclear spectra using the data from  $(p, n)$  quasielastic scattering. One can find corresponding information about the polarization effects in the  $^{48}\text{Ca}$  region in Ref. [3], where the  $^{48}\text{Ca}(p, n) ^{48}\text{Sc}$  reaction with polarized protons leading to the  $0^+$  (6.67 MeV) isoanalogue state was studied, but with theoretical analysis based on microscopical approach for description of nuclear structure and in terms of nucleon-nucleon amplitudes (DWIA). Here we proceed in terms of the Lane model basing on spin-orbit parameters defined in [1] and using the Born approximation for the description of scattering. Similar problems for other target nuclei were also studied in this approach in [4].

It is well known that in the Born approximation polarization effects arising from the spin-orbit potential disappear [5]. Thus to describe these effects one needs to introduce an imaginary part (absorption) into the optical potential, that really means the account of effects beyond the Born approach. We must also include in the real and imaginary parts of the potential the dependence on the incident energy, which was rather high ( $E = 134 \text{ MeV}$ ) in [3]. In [6], [7] the following proposition in the case of volume absorption is presented for the  $V_0$  parameter:  $V_0 = V'_0(1 - 0.0058 \cdot E)$  with  $V'_0 = -52 \text{ MeV}$ , that is rather close to the value of  $-51.5 \text{ MeV}$  obtained by us in [1]. In this case the corresponding absorption term in the optical potential was proposed in [6] in the form of  $i \cdot W_V f(r)$  with  $W_V(\text{MeV}) = -3.3 \cdot (1 + 0.03 \cdot E)$ . Surface absorption is usually given as  $i \cdot W_S(df/dr)$ . For small values of transferred momentum (small angles) both variants of absorption must result in similar descriptions of the scattering process. In the case of  $a \ll R$  this leads to  $W_S \approx -(R/3)W_V$ . So, as an absorption term we use the combination of the form

$$i \cdot W_V [\alpha - (1 - \alpha) \frac{R}{3} \frac{d}{dr}] f(r) \quad (3)$$

with  $0 \leq \alpha \leq 1$ , that leads to polarization effects, independent on  $\alpha$  at small scattering angles, but strongly dependent on  $\alpha$  at large values of transferred momentum. Thus, for the description of polarization effects we use the optical potential of the form (2), but with

$$V_o \rightarrow -51.5 \cdot (1 - 0.0058 \cdot E) - i \cdot 3.3 \cdot (1 + 0.03 \cdot E) [\alpha - (1 - \alpha) \frac{R}{3} \frac{d}{dr}], \quad (4)$$

adopting similar energy dependences for isoscalar and isovector terms of the central nuclear potential.

In Fig.1 one can see the results of our calculations for the analyzing power  $A$  in the case of  $(p, n)$  reaction on  $^{48}\text{Ca}$  leading to the isoanalogue state

$$A_{th} = \frac{d\sigma_{\uparrow\uparrow}/d\omega - d\sigma_{\uparrow\downarrow}/d\omega}{d\sigma_{\uparrow\uparrow}/d\omega + d\sigma_{\uparrow\downarrow}/d\omega} ; |A| \leq 1 \quad (5)$$

together with experimental data and results of microscopical calculations from [3]. Here  $\sigma_{\uparrow\uparrow}$  and  $\sigma_{\uparrow\downarrow}$  are cross sections with the polarization vector  $\vec{\varepsilon}$  of protons parallel or antiparallel to  $[\vec{k}_i \times \vec{k}_f]$ . We see that in the case of surface absorption ( $\alpha = 0$ ) our calculations that use the corresponding spin-orbit parameters from [1] demonstrate good agreement with the experiment up to high values of the scattering angle. At the same time, introduction of the energy dependence into the spin-orbit parameter  $V_{ls}$ , analogous to that for the central nuclear field, leads to poor agreement with the experiment on the analyzing power.

Our calculations with  $\alpha = 0$  give the magnitude of differential cross section for the  $^{48}\text{Ca}(p, n)^{48}\text{Sc}^*$  (I.A.S.) reaction on unpolarized protons at zero angle equal to  $\approx 7.7$  mb/sr, very weakly increasing with increase of the parameter " $\alpha$ ", this cross section sharply diminishes with the increase of the scattering angle and has some structure at  $\Theta_{c.m.} \sim 20^\circ$ . The value presented above may be compared with the magnitude of cross section at zero angle measured in [8] ( $\sim 7$  mb/sr), as well as with the theoretical prediction [8] based on microscopical theory ( $\sim 7.5$  mb/sr).

The following conclusions should be made:

- Experimental data on the isotopical dependence of spin-orbit splitting in nuclei are consistent with the data on polarization effects in  $(p, n)$  quasielastic scattering. The mean field parameters defined in [1] that describe the proton and neutron spin-orbit splittings in nuclei close to  $^{132}\text{Sn}$  and  $^{208}\text{Pb}$ , in particular the  $\beta_{ls}$  one, well reproduce experimental data for  $(p, n)$  quasielastic scattering on  $^{48}\text{Ca}$ .
- Good description of analyzing power at high energy of incident protons with the spin-orbit parameters borrowed from low energy spectroscopy is consistent with supposition about the weak energy dependence of the mentioned optical model parameters.
- Satisfactory description of cross section for the  $(p, n)$  reaction leading to isoanalogue state points to the correct parameterization of the energy dependence of isovector terms in the central nuclear potential used by us.
- The obtained results unambiguously demonstrate a considerable contribution of the surface absorption ( $(1 - \alpha) \geq \sim 0.5$ ) in nuclei.

The author is grateful to B. Fogelberg, H. Mach, V.E. Bunakov and K.A. Mezilev for numerous and useful discussions on the problems of spin-orbit splitting in nuclei.

This work was supported by the Russian Foundation of Fundamental Research (grant No.00-15-96610).

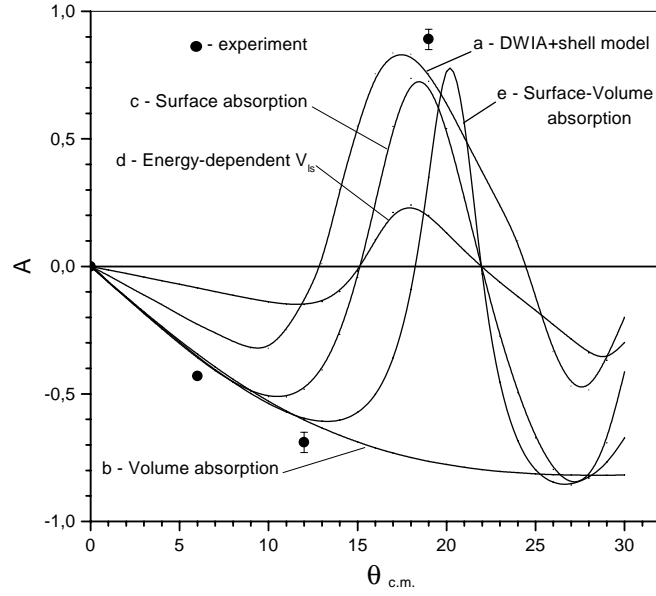


FIG. 1. Experimental data on analyzing power [3] together with results of different calculations: a) DWIA microscopical calculation [3]. b) Our calculation with  $\alpha = 1$  (volume absorption),  $V_{ls} = 33.2 \text{ MeV} \cdot \text{fm}^2$ ,  $\beta_{ls} = -0.6$ . c) Our calculation with  $\alpha = 0$  (surface absorption),  $V_{ls} = 33.2 \text{ MeV} \cdot \text{fm}^2$ ,  $\beta_{ls} = -0.6$ . d) Our calculation with  $\alpha = 0$ ,  $\beta_{ls} = -0.6$ , and energy-dependent parameter  $V_{ls}$ . e) The same as "b", "c", but with  $\alpha = 0.5$ .

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